

# An epidemiological study of acute carbon monoxide poisoning in the West Midlands

Richard C Wilson, Patrick J Saunders, Gillian Smith

## Abstract

**Objectives**—To describe the epidemiology of carbon monoxide (CO) poisoning in a defined population, identifying those at greatest risk from acute poisoning resulting in admission to hospital or death.

**Methods**—A retrospective study with routinely collected information, set in the former West Midlands Regional Health Authority; population of 5.2 million. The data comprised 939 deaths and 701 hospital admissions due to CO poisoning between January 1988 to December 1994. The main outcome measures were age and sex standardised incidence rates (SIRs) for non-intentional, suicidal, and undetermined poisonings for health authorities and the linear relation with socioeconomic deprivation.

**Results**—Overall rate of non-intentional poisonings over the 7 year period was 7.6/100 000, an annual rate of 1.1/100 000. The 7 year rates were highest in people  $\geq 85$ ; men 24.0/100 000 and women 19.7/100 000. For suicides the 7 year rate was 19.6/100 000, an annual rate of 2.8/100 000. The 7 year rates were highest for men of 35–39, 64.1/100 000, and for women aged 45–49, 15.3/100 000. None of the causes of poisoning were related to deprivation. Non-intentional poisonings showed a strong seasonal variation with the highest rates being recorded in the months October to March. Increased rates of poisoning were found in the rural districts of the West Midlands. There seems to have been a decline in suicides coinciding with the introduction of three way catalytic converters on cars.

**Conclusions**—Elderly people and the very young are at the greatest risk from non-intentional CO poisoning and rates are highest in the winter months. Although deaths from non-intentional CO poisoning are declining nationally, in the West Midlands they have remained stable and hospital admissions are increasing. It is not solely an urban phenomenon with rates for non-intentional CO poisoning and suicides higher in the rural districts. Health authorities need to consider all populations in any prevention programme. Further work is needed to establish the extent of the burden of chronic CO poisoning and the impact of catalytic converters on suicides.

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Keywords: carbon monoxide; poisoning; suicide; non-intentional poisoning

An apparent cluster of non-intentional carbon monoxide (CO) poisonings in the North Staffordshire District Health Authority of the West Midlands Region during the winter of 1995–6 led to a regional assessment in line with the plan for chemical incidents and the regional surveillance system.<sup>1,2</sup> This showed that there were no recent epidemiological reviews of CO in the United Kingdom. Studies had been carried out in the United States,<sup>3,4</sup> Switzerland,<sup>5</sup> Denmark,<sup>6,7</sup> Belgium,<sup>8</sup> France,<sup>9</sup> Taiwan,<sup>10</sup> and South Korea,<sup>11</sup> however the results of these studies are not generalisable to the United Kingdom because of the differences in the range of fuels and appliances in use. Therefore, this population study was undertaken to investigate the background to this cluster and the general epidemiology of a largely preventable condition in this country.

## SOURCE

Carbon monoxide is an intermediate product of the combustion of all carbon species and a ubiquitous environmental pollutant. It is a colourless, odourless, tasteless, and non-irritating gas that is slightly lighter than air.<sup>12</sup> This, together with the non-specific and variable symptoms of poisoning, makes CO and the effects of exposure difficult to detect or diagnose.

## EXPOSURE AND HEALTH EFFECTS

Since the replacement of CO rich town gas with natural gas between 1967 and 1972, the number of deaths due to non-intentional poisoning has decreased markedly. However, the number of suicides involving CO, primarily from motor vehicle exhaust gases, has increased dramatically (fig 1) and has been described as the modern self poisoning method.<sup>13</sup>

The principal exposures of CO to the general population are:

- Non-intentional: occur in a number of circumstances, including house fires, poorly maintained or fitted gas fired appliances, petrol

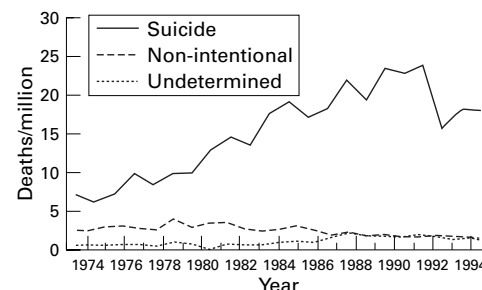


Figure 1 Death rate from non-intentional and suicidal poisonings in England and Wales, 1973–94.

Department of Public Health and Epidemiology, Medical School, University of Birmingham, Edgbaston, Birmingham, UK  
R C Wilson  
P J Saunders

Department of Communicable Disease Control, North Staffordshire Health Authority, Heron House, Great Fenton Business Park, 120 Grove Road, Fenton, Stoke on Trent, UK  
G Smith

Correspondence to:  
Richard C Wilson,  
Department of Public Health and Epidemiology, Medical School, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK.  
Telephone 0044 121 414 7851; fax 0044 121 414 7878; email  
r.c.wilson@bham.ac.uk.

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powered pressure washers, and travelling in the back of lorries.<sup>3 14-16</sup>

- Occupational: traffic police and garage workers may be heavily exposed and fire fighters can experience CO concentrations up to 100 000 ppm in fires.<sup>17 18</sup> Methylene chloride used as a paint stripper is a recognised cause of CO poisoning.<sup>19</sup>

- Suicide: particularly car exhaust poisoning. The introduction of strict exhaust standards in the United States in 1968 led to a reduction in deaths from exhaust poisonings.<sup>20</sup> Although catalytic converters reduce CO emissions considerably, these have only been fitted on new cars in the United Kingdom since 1993.

Carbon monoxide reacts with haemoglobin to form carboxyhaemoglobin, reducing the total oxygen carrying capacity of the blood. This affinity is >200 times than for the formation of oxyhaemoglobin. Also, CO shifts the dissociation curve of any remaining oxyhaemoglobin to the left, thereby reducing even further the liberation of oxygen. Consequently, tissue anoxia is much greater than simply the effects of the loss of oxygen carrying capacity.<sup>21</sup> There is also some evidence that CO has a toxic effect on cellular respiration.<sup>19</sup> The pattern of exposure, age, lung diffusion capacity, barometric pressure, and alveolar ventilation rate are all important factors in the increase of carboxyhaemoglobin.<sup>22</sup>

Vulnerable groups include fetuses, elderly people, and those with heart disease, anaemia, and pulmonary disease.<sup>23</sup> Acute exposure to high concentrations of CO can be fatal due to hypoxia<sup>21</sup> and chronic exposure is associated with cardiovascular attacks,<sup>24-26</sup> neurobehavioural,<sup>27 28</sup> fibrinolytic,<sup>29</sup> and perinatal symptoms.<sup>30</sup> Symptoms of repeated low level exposures include headache, nausea, confusion, motor and sensory performance, chest pain, and diarrhoea.<sup>22 23</sup> There is also evidence of delayed neurological effects after apparent recovery.<sup>31</sup>

#### DATA

For the period January 1988 to December 1994, all completed consultant episodes in which evidence of CO as a main or supplementary cause of illness was reported were extracted from the hospital episode statistics of the West Midlands Region. These record patient details (date of birth, sex, postcode of residence), diagnostic data (up to six diagnoses codes), and outcome measures (duration of stay and discharge destination). Deaths from CO for all West Midlands residents were extracted from standard death tapes from the office of population censuses and surveys (OPCSs) for the same period.

Records were selected when at least one of the following international classification of diseases ninth revision codes (ICD-9)<sup>32</sup> were given:

A986—Toxic effect of CO;

E867—Non-intentional poisoning by gas distributed by pipeline;

E868—Non-intentional poisoning by other utility gas and CO;

E951—Suicide and self inflicted poisoning by gases in domestic use;

E952—Suicide and self inflicted poisoning by other gases and vapours;

E981—Poisoning by gases in domestic use, undetermined whether non-intentionally or purposely inflicted;

E982—Poisoning by other gases, undetermined whether non-intentionally or purposely inflicted.

When an unspecified or other unlisted pollutant was recorded that episode was rejected unless another diagnosis code specifically named CO as a constituent cause. The poisonings associated with fires are excluded, as these relate to preventing fires rather than CO poisoning themselves.

Incidents were categorised into non-intentional, suicide, and undetermined poisonings based on the ICD-9 codes. These categories are analogous with the verdicts reached by the coroner when the return of an open verdict is flagged here as undetermined.

Concerns have been raised about the accuracy of the reported underlying cause of death.<sup>33</sup> In this study the accuracy of the diagnoses is unlikely to be affected as by their nature deaths from CO are likely to be viewed suspiciously and further investigated in the coroner's court. This should mean that the codes selected would capture all incidents of CO poisoning in the death data.

The Health and Safety Executive (HSE) was approached for those incidents recorded under the Reporting of Injuries, Diseases, and Dangerous Occurrences Regulations 1985 (RIDDOR)<sup>34</sup> for the West Midlands Region. Data were available by financial year for the period 1 April 1987 to 31 March 1995.

As non-intentional CO poisoning is potentially fatal, it is necessary to link the data sets to assess the true scale of the problem. For suicides, both those attempts that result in death and those which fail together must be considered as related, but different, phenomena.<sup>35</sup> Links between the two data sets are based on date of birth, sex, postcode, and date of incident.<sup>36</sup> A separate linking process is carried out on the hospital episode data set to identify patients rather than episodes, of which there may be more than one per admission.

#### Method

To examine variations in the different categories of poisoning incidents, it is necessary to account for the variations in the denominator populations. Therefore, the frequency counts are directly age and sex standardised into rates per 100 000 with the 1991 census as the standard regional population.

The relation between socioeconomic deprivation and CO poisoning was tested by ordinary least squares regression. The 826 electoral wards of the region were ranked in ascending Townsend score<sup>37</sup> and the population divided into 10 roughly equal sized bands. Individual people are allocated to a population band by their postcode of residence. For each band a directly age and sex standardised incident rate was calculated. The rates were

Table 1 The recorded number of deaths, admissions, and overall incidents due to carbon monoxide poisoning from January 1988 to December 1994 in the West Midlands Regional Health Authority

	1988	1989	1990	1991	1992	1993	1994	Total
Admissions:								
Non-intentional	31	37	29	54	47	50	55	303
Suicide	32	43	47	60	51	60	50	343
Undetermined	5	15	1	8	9	6	11	55
Total	68	95	77	122	107	116	116	701
Deaths:								
Non-intentional	13	15	12	18	27	12	13	110
Suicide	102	93	124	100	101	103	85	708
Undetermined	14	21	18	17	14	24	12	120
Total	129	129	154	135	142	139	110	938
Incidents:								
Non-intentional	42	52	41	72	74	62	68	411
Suicide	134	136	171	158	151	162	136	1048
Undetermined	20	35	19	25	23	30	22	174
Total	196	223	231	255	248	254	226	1633

then plotted against the population weighted Townsend score for that band and the linear relation was calculated.

### Results

Over the period January 1988 to December 1994, 701 patients were admitted to hospital as a result of CO poisoning, of which 43.2% (303/701) were the result of non-intentional poisoning, 48.9% (343/701) after attempted suicide, and the remaining 7.9% (55/701) undetermined. In the same period 939 deaths were reported. Most of the deaths were the result of suicide (75.5% (708/938)), 12.8% (120/938) undetermined, and 11.7% (110/938) non-intentional. The linked data set recorded 1633 unique incidents of which 25.2% (411/1633) were non-intentional, 64.2% (1048/1633) suicides, and the remaining 10.7% (174/1633) undetermined. The average duration of stay in hospital was 4.2 days, ranging from 1–135 days. Only 1.4% (10/701) patients died at hospital, of which three were non-intentional poisonings,

five suicides, and two undetermined suggesting that if patients get to hospital they are likely to survive.

### NON-INTENTIONAL POISONINGS

The number of admissions for non-intentional poisoning in the West Midlands had increased over the 7 years, although the number of fatal poisonings had remained constant (table 1).

Considering the aggregated dataset, the most common source of non-intentional poisonings is domestic fuel (52.3%), either from piped gas (ICD-9 E867), mobile gas containers (ICD-9 E868.0), or other domestic fuels such as coal, coke, and paraffin (ICD-9 E868.1 and E868.3). The motor car is responsible for 12.3% of poisonings (ICD-9 E868.2). The remaining 35.4% was caused by unspecified sources (ICD-9 E868.9).

Table 2 The rate of suicidal deaths per million population, in England and Wales, with motor vehicle exhaust gases and other methods from 1984 to 1994

Year	Suicides involving motor vehicle exhaust gases	Suicides from all other methods
1984	19.17	70.67
1985	17.18	65.70
1986	18.17	61.41
1987	21.97	62.31
1988	19.51	54.25
1989	23.44	54.51
1990	22.96	53.44
1991	23.92	53.62
1992	15.95	53.03
1993	18.51	53.69
1994	18.13	51.82

Source=Office of Populations, Censuses and Surveys mortality statistics: cause; numbers 12–21.

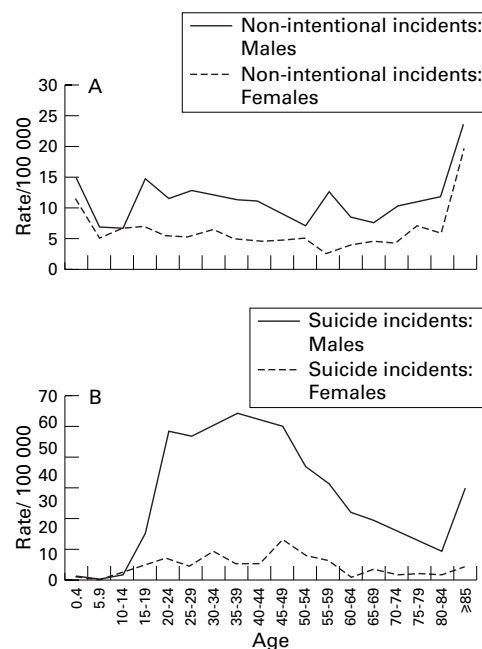


Figure 2 Age-sex specific rates of incidents of (A) non-intentional and (B) suicidal CO poisonings (January 1988 to December 1994) in the West Midlands Regional Health Authority.

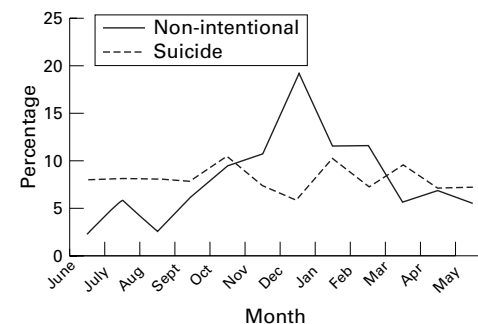


Figure 3 The seasonal variations in the incidents of non-intentional and suicidal CO poisonings (January 1988 to December 1994) in the West Midlands Regional Health Authority.

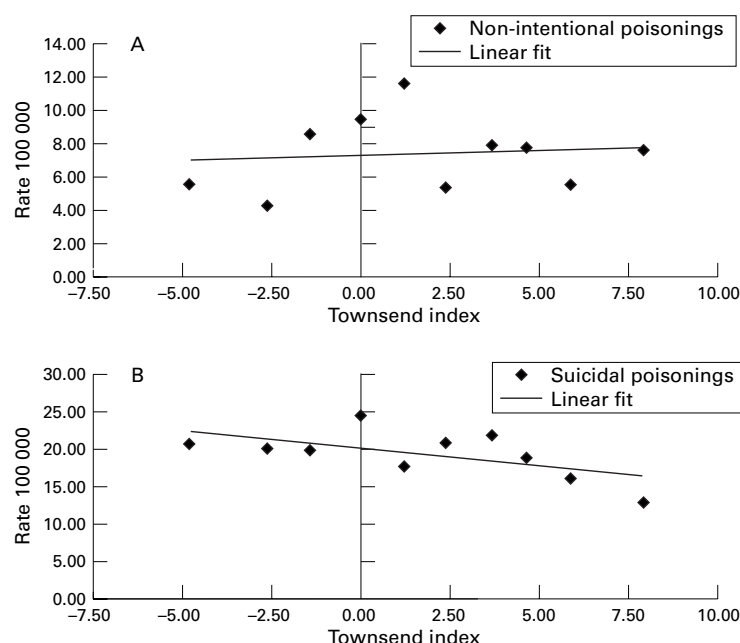


Figure 4 The relation between the incidence of (A) non-intentional and (B) suicidal CO poisonings and the Townsend index of socioeconomic deprivation (January 1988 to December 1994) in the West Midlands Regional Health Authority.

There were 12 patients admitted to hospital with poisonings related to occupation (ICD-9 E868.8). Thirteen notifications of workplace CO poisonings were made under RIDDOR.

#### OCCUPATIONAL POISONINGS

The risk of poisoning was greatest among men accounting for 64.1% of incidents. The most at risk group is elderly people (>85); 24.0/100 000 men, 19.7/100 000 women. They had an incident rate almost twice that of the next most at risk group, (aged 0 to 4 years); 15.0/100 000 male, 11.1/100 000 female (fig 2 A). There was an increased level in 15–19 year old males (14.7/100 000) due predominantly to the failure of mobile gas containers. There was one fatality for every 4.3 poisonings. In the 0–4 year olds, the ratio of fatal to non-fatal poisoning was 1:3.6. The ratio subsequently rose to a peak of 1:19.5 in 10–14 year olds, then declined with age to close to 1:1 over the age of 60.

#### SUICIDES

The most common method of suicide with CO was by motor vehicle exhaust gases (ICD-9

E952.0, 74.8%). There was a high percentage (21.8%) of unspecified sources (ICD-9 E952.9). Suicide and attempted suicide by CO was predominantly committed by males (85.3%), with a broad age distribution (fig 2 B). Overall the suicide rate exceeded that of attempted suicide by a factor of >2, rising from 0.71 in 15–19 year olds to a peak of 5.5 in 70–4 year olds.

The highest 7 year rate for males was 64.1/100 000 in the 40–4 age group, and for females, 15.3/100 000 in those aged 50–4. Record linkage identified 11 people who attempted suicide and repeated the attempt with the same method, most within a year, of whom three succeeded.

The suicide rate from motor vehicle gases increased steadily to 1992 and subsequently declined (fig 1) from a high of 23.9/1 000 000 deaths in 1991 to 15.95/1 000 000 in 1992, although all other methods decreased (table 2). Suicides from all other methods remained relatively constant around 53.0/1 000 000 (table 2).

#### UNDETERMINED CAUSES

In the hospital episode data there were no notable patterns in the undetermined incidents. The greatest proportion of undetermined deaths (48.3%) related to ICD-9 E982.0, “undetermined whether non-intentionally or purposely inflicted from motor vehicle exhaust gas”. These undetermined deaths had a similar demography to that of suicides. Analyses were repeated on suicides including the undetermined E982.0 deaths but these did not notably change the results and hence are not reported here.

#### SEASONAL VARIATIONS

Non-intentional poisonings were highly correlated with the winter months (fig 3). The rate of events increased from September, peaked in December and remained increased to the end of March. Suicides remained steady across the year with increased rates in January, March, and October.

#### DEPRIVATION

For non-intentional poisonings there was no significant relation between incidence and deprivation ( $p=0.79$ , NS,  $r^2=0.01$ ). However, for suicidal poisonings there was a weak negative relation ( $p=0.07$ , NS,  $r^2=0.36$ , fig 4 A, B).

Table 3 Age and sex standardised incident rates per 100 000 (95% CIs) for all causes of carbon monoxide poisonings (January 1988 to December 1994) for the 13 District Health Authorities of the West Midlands Regional Health Authority

District Health Authority	Non-intentional	Suicides	Undetermined
Hereford	10.72 (10.63 to 10.80)	28.18 (28.03 to 28.33)	1.39 (1.35 to 1.42)
Worcester	2.40 (2.37 to 2.43)	26.35 (26.26 to 26.44)	1.65 (1.63 to 1.67)
Shropshire	12.54 (12.50 to 12.57)	22.14 (22.09 to 22.20)	2.70 (2.68 to 2.72)
North Staffordshire	10.52 (10.49 to 10.56)	26.52 (26.47 to 26.57)	3.63 (3.62 to 3.65)
Coventry	8.17 (8.13 to 8.21)	25.16 (25.08 to 25.24)	1.48 (1.46 to 1.50)
Dudley	4.55 (4.52 to 4.58)	21.48 (21.42 to 21.55)	2.55 (2.53 to 2.57)
Sandwell	5.77 (5.73 to 5.81)	14.68 (14.62 to 14.74)	1.43 (1.41 to 1.45)
Solihull	5.63 (5.57 to 5.68)	16.50 (16.42 to 16.59)	3.08 (3.04 to 3.13)
Walsall	5.32 (5.28 to 5.36)	10.80 (10.74 to 10.86)	4.69 (4.65 to 4.73)
Wolverhampton	8.19 (8.14 to 8.25)	10.72 (10.66 to 10.78)	9.12 (9.06 to 9.18)
South Birmingham	6.25 (6.23 to 6.28)	16.49 (16.44 to 16.53)	0.94 (0.93 to 0.95)
North Worcester	4.03 (4.00 to 4.06)	21.30 (21.23 to 21.38)	2.21 (2.18 to 2.23)
South Staffordshire	7.74 (7.1 to 7.76)	17.11 (17.08 to 17.14)	8.66 (8.63 to 8.68)
Warwickshire	9.63 (9.1 to 9.66)	22.45 (22.41 to 22.50)	1.63 (1.61 to 1.64)
North Birmingham	7.58 (7.55 to 7.60)	15.69 (15.66 to 15.73)	2.40 (2.39 to 2.42)



## ACROSS HEALTH AUTHORITIES

There were noticeably high rates of non-intentional poisonings in the more rural districts of Shropshire and North Staffordshire. For suicides the rates were even higher in these rural districts (table 3). The incidence of undetermined poisonings was noticeably high in Wolverhampton and South Staffordshire.

**Discussion**

The common perception of those at the greatest risk from non-intentional CO poisoning is students in bed-sitting rooms. At the time of the 1991 census, there were >12 000 students living in shared accommodation, in the West Midlands. However, as this study has shown, elderly and very young people are at the greatest risk of non-intentional poisoning. They are the ones less likely to be able to take preventive action. They are also at a higher risk of dying with the ratio of deaths to admissions being up to 20 times higher than in the 10–14 age group. It seems that they are either less likely to receive treatment in time or to survive the insult. It is especially important that elderly people are removed as soon as possible from the source of CO as they are at particular risk.<sup>21</sup>

The time of greatest danger is during the winter months. This is not unexpected as the major cause of non-intentional poisonings relates to domestic heaters and these are likely to be used most heavily at this time. If the rates found here were replicated across England and Wales about 500 people a year would have an acute non-intentional poisoning.

It is possible that the figures presented here could be biased due to the method of data capture. This is especially true of the hospital episode statistics. On presentation, if the clinician does not suspect CO poisoning, it is likely that the patient's condition may be recorded as an unspecific condition or general symptoms. It is not possible to judge when this occurs. In particular, it is likely to lead to an underestimation of incidents of non-intentional poisonings, as the patient will usually have been found in a normal domestic situation. The non-intentional rate could be artificially increased if patients attending after a failed suicide attempt conceal this fact. However, such incidences are likely to be recorded as undetermined poisoning.

As well as the possibility of incorrect coding there is a high proportion of undetermined poisoning. This reflects either a lack of evidence presented at the Coroner's Court and hence recorded on the death certificate, lack of precision in diagnosis coding, or the inability of the medical staff to ascertain from the patient the most likely origin of intoxication.

Nicholson suggests that the underestimation of suicides through the use of open verdicts would explain much of the variation between districts.<sup>38</sup> This might suggest a reason for the low suicide and high undetermined rates in South Staffordshire and Wolverhampton, both of which have notably high undetermined rates. Sainsbury and Jenkins state that the randomised occurrence of such errors permits the comparison of rates among sociodemographic groups and over time.<sup>39</sup> The fact that including

those deaths that are undetermined, whether non-intentionally or purposely inflicted from motor vehicle exhaust gas (ICD-9 E982.0), with suicidal poisonings in the analyses did not change the results supports this finding.

The suicide rate exceeds that of known attempted suicide by a factor >2, making this a depressingly successful way of taking one's life. This is different from most other methods, in which attempts outnumber successes.<sup>40</sup> The frequency of this method has been attributed to the news coverage such deaths draw and the popularity of hatchback cars, which require a shorter hosepipe.<sup>13</sup> The increased access to a car in rural districts could explain much of the regional variation in suicidal poisonings.

The frequency of suicide by motor vehicle exhaust gases has led to it being described as the modern self poisoning method.<sup>13</sup> In 1992, O'Brien and Tarbuck suggested that the introduction of strict controls on exhaust emissions might have a beneficial effect on the rate of suicides by this method.<sup>41</sup> This view is supported by work carried out in the United States, which postulated that the introduction of catalytic converters on new motor cars and stricter emission controls could reduce the number of suicidal deaths from the inhalation of exhaust fumes.<sup>42–43</sup> There have been several patient studies published that provide anecdotal evidence on the relation between cars fitted with catalytic converters and failed suicides.<sup>44–45</sup>

This study found that up to 1992 the number of suicides with motor vehicle exhaust gases increased steadily (fig 1). However, in that year the rate of suicides with motor vehicle exhaust gases dropped. Contemporaneously the percentage of the United Kingdom car fleet with catalytic converters fitted increased almost 10-fold from 0.4% in 1991 to 3.9% in 1992.<sup>46</sup> As the alternative methods of suicide have remained little changed it seems that there is little or no substitution occurring.

If the levels of suicides with motor vehicle exhaust gases had continued at the pre-1992 rate, then it is likely that the introduction of catalytic converters may have prevented over 950 suicides in England and Wales in the 3 years from 1991 to 1994. This is not likely to be a permanent reduction as people will quickly become aware of the ineffectiveness of this method and adopt alternatives. Efforts still need to be directed at reducing the underlying sociomedical causes as catalytic converters give health professionals a unique second chance to aid the victim. Further work will be required to verify this effect and the numbers of deaths should be monitored to identify what, if any, substitution occurs.

The absence of a linear relation between socioeconomic deprivation and non-intentional poisoning is perhaps not unexpected as the legislation and health promotion work has concentrated on landlords and students who tend to be concentrated in areas of deprivation. A descriptive study carried out in north Staffordshire showed no common factors, including socioeconomic status, linking several cases of CO poisoning in the winter of 1995.<sup>47</sup> Again, work by The Carbon Monoxide

and Gas Safety Society (CO-GAS) reflected the risk to all households as they report that it can affect all types of residence and all social classes.<sup>48</sup>

The weak linear relation between suicidal poisonings and deprivation contrasts with that reported elsewhere.<sup>39</sup> This is perhaps not unexpected as access to the primary method of suicide, motor exhaust gas, is likely to be higher in more affluent communities and that one of the components of the Townsend score is lack of car ownership.

It is of particular concern that non-intentional poisonings, which are largely preventable, are not declining further. The problem does not seem to be in treatment as the hospital survival rate is 98.6%, but rather in the public awareness of the dangers of poorly maintained or fitted heating and cooking appliances. The study shows that the problem is seasonal with elderly and young people at greatest risk and that is not solely an urban or deprivation problem. It is recommended that health authorities consider their whole population in any health promotion intervention. They should also consider the particularly at risk groups (elderly and very young people) and be aware that rural, as well as urban, parts of their district are important. Campaigns need to involve a range of agencies including the Health and Safety Executive (the principal United Kingdom government body responsible for enforcing health and safety legislation), local authority, Council of Registered Gas Installers (CORGI), and the fuel suppliers. It should also be considered whether, as well as recommending the correct installation and annual servicing of gas appliances by CORGI registered engineers, use of audible CO monitors should be recommended to the public.

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